(उत्तर) भौरा रसिया फूल का कली कली रस
हरजाई के मित्र को पास न बैठन दे .

Translation.

O Champá (flower) thou hast three properties in thee:
Colour, beauty and fragrance,
(But) thou hast one defect, that the black-bee does not come near thee.

Reply. The black-bee is the lover of flowers and it tastes the sweets of numerous flowers.
I do not allow the friend of prostitutes to come near me.

Notes from Varáha Mihira's Pañchasiddhántiká.—By G. Thibaut, Phil. Dr.

PART I.

The mean motions of the planets according to the Su'rya and Romaka Siddha'ntas.

We are at present fairly well-acquainted with the general character of Hindú Astronomy and—among European scholars at least—there prevails no longer any doubt that the system exhibited in works like the Súrya Siddhánta, the Laghu-A'ryabhaṭíya, etc. is an adaptation of Greek science. The time to which books like the Súrya Siddhánta must be ascribed from internal data, the date of A'ryabhaṭa,—if not *the* oldest, at least one of the oldest of the scientific Hindú Astronomers—which we know from his own statement, the fundamental similarity of the methods employed by the Greeks on the one and the Hindús on the other side, the fact of terms of unquestionably Greek origin being met with in Indian astronomical works, and lastly the testimony which the Hindú writers themselves bear to the proficiency of the Yavanas in the Jyotisha S'ástra more than suffice to convince impartial judges that the enormous progress which a book of the class of the Súrya Siddhánta marks on works of the nature of the Jyotisha Vedánga was not effected without help coming from the West.

But although the general fact of transmission is acknowledged the details of the process still stand in need of much elucidation, and we shall not be able to claim a full understanding of the position of the

Hindú system before we have succeeded in tracing the single steps of the gradual transformation by which it arose from its Greek prototype, and in assigning the reasons of the many important points of divergence of the two. Whether this task will ever be accomplished completely is doubtful. The chief obstacles in the way of success are the loss of several of the most important early Siddhántas which, as their names indicate, were specially connected with Western science, and the uncertainty whether the form in which the preserved Siddhántas have come down to us is the original one or has, in the course of time, undergone alterations. All we can do is to study with the greatest possible care those astronomical books which may to a certain extent make up for the mentioned loss, and enable us to gain some insight into the genesis and original condition of what we may call—in order to distinguish it from earlier and greatly inferior attempts—Scientific Hindú Astronomy.

Among the works belonging to that class by far the most important is the so-called Pañchasiddhántiká by Varáha Mihira. References to this treatise which—as its name implies—is founded on five Siddhántas, were occasionally made by European scholars from the first time when Hindú Astronomy began to attract attention. Manuscripts of the work itself indeed were not forthcoming for a long time, and the important quotations made from it by Colebrooke and subsequent writers, among whom Professor Kern is to be mentioned in the first place, were taken from later astronomical books, chiefly from the Commentary on Varáha Mihira's Bṛihat-Samhitá by Bhaṭṭotpala who in many places endeavours to render his explanations of the latter work more lucid by extracting corresponding passages from the Pañchasiddhántiká. These quotations were, however, amply sufficient to show the extraordinary importance which the treatise in question possesses for the history of Indian astronomy, and it was therefore most welcome news to all students of Sanskrit when Dr. Bühler, whose sagacity and activity in tracing and rescuing from destruction really valuable Sanskrit books stand in no need of further praise, was able to announce in 1874 the discovery of a complete manuscript of the Pañchasiddhántiká. A second somewhat more correct manuscript of the work was later on discovered by the same scholar. Both manuscripts were purchased for the Bombay Government.

Nothing could now be more desirable than an early edition and translation of the entire Pañchasiddhántiká; but unfortunately there are considerable obstacles in the way of a speedy realization of such a wish. In the first place, the two available manuscripts are exceedingly, in more than one case, hopelessly incorrect. In the second place, the text, even if presented in a correct and trustworthy shape, offers to the interpreter unusually great difficulties whose special nature will be set into a clearer light by a short consideration of the class of books to which the Pañchasiddhántiká belongs.

The Pañchasiddhántiká is a so-called karaṇagrantha. The only definition of the term " karaṇa " by a European scholar of which I know is the one given by Professor Kern, who says (preface to the Bṛihat Saṃhitá, p. 24) that a karaṇa differs from a Siddhánta in this respect, that while in the latter the calculations refer to the beginning of the Yuga, in the former they refer to the S'aka era. This statement is quite correct, but not full enough to give an adequate idea of the nature of a karaṇa. A karaṇa may be defined as a practical treatise on astronomy, *i. e.*, a treatise which enables the astronomer to execute the common astronomical calculations known to the Hindús with the greatest possible ease and despatch. While a Siddhánta explains the general principles of the Hindú astronomical system, and thereby enables the attentive student to construct for himself the rules which are to guide his calculations, a karaṇagrantha exhibits those rules ready made and reduced to the most practical and succinct shape without, however, explaining the theory on which they are based. A karaṇagrantha is thus sufficient for all practical purposes, but not really intelligible without the study of the Siddhánta from which its rules are derived. That it takes for the starting-point of its calculations not the beginning of the Yuga or kalpa but that of the S'aka era is of course merely a consequence of the desire to render all calculations as easy and short as possible. The most important books of the karaṇa class are the Grahalághava by Gaṇeśa Daivajna, the Bhásvatí by S'atánanda, the Karaṇakutúhala by Bháskara and, among more ancient works, the Khaṇḍakhádyaka by Brahmagupta and, holding the first rank in importance, the Pañchasiddhántiká.

This latter work has, however, a wider scope than an ordinary karaṇagrantha. It does not form the practical complement of one Siddhánta only, as for instance the karaṇakutúhala does with regard to the Siddhánta S'iromaṇi, but as its name indicates, it gives rules in accordance with five different Siddhántas. These Siddhántas are, as we now may see from the introductory verses of the Pañchasiddhántiká itself, while formerly our information regarding them was derived from the Bṛihat Saṃhitá and its commentary, the Saura, Pauliśa, Romaka, Vásishṭha and Bráhma or Paitámaha Siddhántas. Of these five Siddhántas only the Saura or Súrya Siddhánta is known to exist at present. The Pauliśa, Romaka, Paitámaha Siddhántas appear to be lost; I am doubtful whether the Vásishṭha Siddhánta to which Varáha Mihira refers has come down to our time or not. We are thus on the whole not in a position to elucidate the highly condensed and often altogether enigmatical rules of the Pañchasiddhántiká by referring to the Siddhántas on which they are founded, but must explain them by themselves as well as we can, availing ourselves of the fragmentary collateral information which may be derived from other sources, and must finally attempt to reconstrue from the karaṇa rules the leading features of the Siddhántas on which they were founded. The latter part of the task is of course the most important, but at the same time the most difficult one, and we shall for the present succeed in it only very partially. Were it not that Varáha Mihira has allowed himself in many points to be more circumstantial than ordinary karaṇa-writers are, so that the Pañchasiddhántiká may in fact be said to occupy a kind of intermediate position between a karaṇa and a Siddhánta, the task would be an altogether hopeless one. As it is, it remains difficult enough and only the manifest importance of the book can maintain the zeal of the student whose efforts at unravelling the sense of the obscure stanzas are foiled more than once. There are of course a considerable number of passages which are by no means difficult to understand, some entire chapters even fall under that category; but then those chapters and passages are easy because they contain no matter new to us and merely restate what we already know from other sources. The chapters which add to our store of knowledge are throughout difficult, some of them so much so that there is no chance of their being fully understood until better manuscripts of the Pañchasiddhántiká are found. Other passages again, although difficult, may be explained satisfactorily. Some of this latter class, *viz.*, those treating of the mean motions of the planets according to two Siddhántas will form the subject of this paper.* A few introductory remarks on the contents of the entire work and the consideration of a few specially interesting passages will be premised before we enter on our special task.

The Pañchasiddhántiká appears to be divided into eighteen adhyáyas, although the exact number may be a matter of some doubt, as in the manuscripts the endings of the chapters are not very clearly marked, and

* I may mention here that I am engaged, with the assistance of Pandit Sudhákara one of the foremost Jyotishis of Benares, in preparing an edition and translation of the entire Pañchasiddhántiká as far as the deficiencies of the manuscripts etc. will allow. But as it is uncertain when this task will be accomplished, I think it advisable to publish in the interim some of the more interesting results. I avail myself of this opportunity to acknowledge the very valuable assistance I have received from Pandit Sudhákara in preparing the present paper. He has verified many of my calculations and in some points tendered original suggestions which were most useful. I specially mention his advice to calculate the kshepa quantities of the Súrya Siddhánta from the beginning of the Kalpa, an advice the carrying out of which led to most satisfactory results.

the numbering of the stanzas is carried on through several adhyáyas. The first adhyáya, called karaṇávatára, contains some introductory verses, a rule for the calculation of the ahargaṇa, statements regarding the different yugas used in the Pauliśa, Romaka, Súrya Siddhántas, and some rules regarding the calculation of the regents of the years, months, etc. The second very short adhyáya is called at its end nakshatrádichheda and apparently contains rules about the mean places of the moon, length of day and night, shadow, etc. The third adhyáya is marked at the end "Pauliśa Siddhánta" and contains the most important rules for the calculation of the mean place of the sun, the true places of sun and moon, the moon's node, latitude, terrestrial longitude, ayana, etc. The fourth adhyáya, marked merely as "karaṇádhyáyaś chaturthaḥ" contains the table of sines and matter corresponding to that of the third adhyáya of the Súrya Siddhanta. The very short fifth adhyáya is entitled S'aśidarśaṇam. The sixth adhyáya contains chandragrahaṇam, *i. e.*, the rules for calculating lunar eclipses according to the Pauliśa Siddhánta, the matter of all the preceding chapters having been merely preliminary to the calculation of eclipses. The seventh adhyáya treats of solar eclipses "Pauliśa siddhánte ravigrahaṇam." The eighth chapter treats of the calculation of solar eclipses according to the Romaka Siddhánta and contains at the same time all the general information about the Romaka Siddhánta which the Pañchasiddhántiká affords. The ninth adhyáya has for its subject the calculation of solar eclipses according to the Súrya Siddhánta with preliminary statements about the mean motions, etc. of sun and moon. The tenth adhyáya treats of lunar eclipses according to the same Siddhánta. The eleventh adhyáya called at its close "avarṇanátyekádaśo 'dhyáyaḥ" contains additional matter about eclipses. The twelfth very short adhyáya "paitámahasiddhánte dvádaśo 'dhyáyaḥ" is the only chapter which treats of the Paitámaha or Bráhma Siddhánta. The thirteenth adhyáya "trailokyasamsthánam" contains information akin to that which is found in the twelfth chapter of the Súrya Siddhánta. The fourteenth adhyáya "chhedyakayantráṇi" gives information about astronomical instruments, etc. The fifteenth adhyáya "jyotishopanishad" states the differences produced in eclipses of the sun by difference of locality; the different opinions about the beginning of the day, etc. The sixteenth adhyáya "súryasiddhánte madhyagatiḥ" states the mean motions of the planets according to the Súrya Siddhánta. The seventeenth adhyáya "tárágrahasphuṭíkaraṇam" gives the rules for calculating the true places of the planets. The last adhyáya "Pauliśasiddhánte tárágraháḥ" contains rules about the heliacal rising and sitting etc. of the planets, apparently according to the Pauliśa Siddhánta.

The introductory verses in which Varáha Mihira states the purport of the entire Pañchasiddhántiká run as follows :—

दिनकरवसिष्ठपूर्वान् विविधमुनीन्द्रान् प्रणम्य भक्त्यादौ ।
जनकं गुरुं च शास्त्रे येनास्मिन्नः कृतो बोधः ॥
पूर्वाचार्यमतेभ्यो यच्छ्रेष्ठलघुस्फुटं बीजम् ।
तत्तद्विहाविकल्पमहं* रहस्यमभ्युद्यतो वक्तुम् ॥
पौलिशरोमकवासिष्ठसौरपैतामहास्तु पञ्च सिद्धान्ताः ।
पञ्चभ्यो द्वावाद्यौ व्याख्यातौ लाटदेवेन ॥
पौलिशतिथिः† स्फुटोऽसौ तस्यासन्नस्तु रोमकप्रोक्तः‡ ।
स्पष्टतरः सावित्रः परिशेषौ दूरविभ्रष्टौ ॥
यत्तत्परं रहस्यं भ्रमति मतिर्यत्र तन्त्रकाराणाम् ।
तदहमपहाय मत्सरमस्मिन्वच्ये ग्रहं भानोः ॥
दिक्स्थितिविमर्दकर्णप्रमाणवेला ग्रहाग्रहाविन्दोः ।
ताराग्रहसंयोगं देशान्तरसाधनं§ चास्मिन् ॥
सममण्डलचन्द्रोदययन्त्रच्छेद्यानि शाङ्कवच्छाया|| ।
उपकरणाद्यहज्यावलम्बकापक्रमाद्यानि ॥

These verses are followed by the rule concerning the calculation of the ahargaṇa which will be considered later on. In the last chapter the author names himself as Varáha Mihira of Avanti.

I further extract a statement found in the 3rd chapter which is of considerable interest as containing a very clear indication of the dependence of Hindú astronomy on Greek science. We read there:

यवनान्तरजा नाड्यः सप्तावन्त्यां¶ त्रिभागसंयुक्ताः ।
वाराणस्यां त्रिकृतिः साधनमन्यत्र वच्यामि ॥

"The náḍís arising from the difference in longitude from Yavana, (*i. e.*, Yavanapura) are seven and a third in Avanti, nine in Benares; the method of ascertaining them I will state elsewhere."

The verse contains a statement of the difference in longitude between Ujjain and Benares on the one side and Yavanapura on the other side. That by the latter name (which occurs in another place of the Pañchasiddhántiká also) we have to understand Alexandria has been remarked by Professor Kern already; the passage we are considering at present

* A. तत्त्कद्विहाविल्पम॰ B. तत्तद्विहाखिल्पम॰

† A. ॰तिथिस्फु॰ B. ॰तिथः स्फु॰

‡ A. ॰मकः

§ A. ॰सावनं

|| ? A. ॰च्छेप्रानिता (ड added in margin) वच्छाया B. छेद्यानिताच्छवच्छाया.

¶ Both MSS. ॰वन्त्याखिभा॰

furnishes the proof. The real eastern longitude (from Greenwich) of Ujjain is 75° 51′ 45″, that of Benares 83° 3′ 4″, that of Alexandria 29° 52′; therefore, the seconds being neglected, Ujjain is in 46° E. Long. Benares in 53° 11′ E. Long. from Alexandria. If we now, on the other hand, calculate the difference in longitude of the mentioned three places from the difference in time stated by Varáha Mihira we obtain 44° as the longitude of Ujjain from Alexandria and 54° as the longitude of Benares from the same place. The error involved in Varáha Mihira's determination is not inconsiderable, but not greater than might have been expected, certainly not too great for our assuming with confidence that Yavanapura is to be identified with Alexandria.* As a transfer of Hellenic astronomy to India could not have taken place without some determination of the interval in longitude we might assume such a determination to have been made even if no trace of it had been preserved in India; still it is satisfactory to find the determination explicitly stated in the book which professes to give an account of the fundamental Siddhántas.

Before leaving this subject we must refer to another passage of the Pañchasiddhántiká which is quoted by Bhaṭṭotpala, and which has been supposed to contain likewise a statement about the difference in longitude between Ujjain and Alexandria. It occurs in the 15th adhyáya and need not be reprinted here in full as it has already been published by Professor Kern in his paper on some fragments of Áryabhaṭa, Journal of the Royal Asiatic Society, Vol. XX, 1863 and again in the Preface to his edition of the Bṛihat Saṃhitá, p. 53. The two lines immediately concerning us here are given by Professor Kern, as follows:

रव्युदये लङ्कायां सिंहाचार्येण दिनगणोऽभिहितः ।
यवनानां निशि दशभिर्मुहूर्तैश्च तद्ग्रहणात् ॥

and rendered "Sinhácharya states the sum of days (to begin) from sunrise at Lañká and, if we adopt this, they must begin in the country of the Yavanas at the time that ten muhúrtas of the night are past." From this Professor Kern concludes that in the opinion of Varáha Mihira the meridian of Yavana-pura has a longitude west from the meridian of

* Professor Kern notices the possibility of Yavanapura being not Alexandria but Constantinople, but rejects it on the ground of no first meridian ever having been drawn over the latter place. If we identified Yavanapura with Constantinople we should reduce the above-mentioned error of longitude by one degree; but nevertheless its identification with Alexandria is much more likely if we consider firstly the general importance of Alexandria; secondly, its geographical position with regard to India, and thirdly, its having been the place where the system of Greek astronomy was finally elaborated.

Lañká, of 60 degrees. (See Preface, p. 54.) This translation of the text as given by Bhaṭṭotpala and the inference he draws from it are indeed quite correct; but we see at once that the passage as it stands cannot be reconciled with the one translated above from which there results a difference of longitude amounting to 44° only. The apparent contradiction is solved when we turn to the text of the Pañchasiddhántiká as exhibited in the two manuscripts available at present. For there the reading at the conclusion of the second line is not तद्ग्रहणात् but तद्गुरुणा, so that we have to translate "Siṃháchárya states the sum of days to begin from sunrise at Lañká; when ten muhúrtas of the night of the Yavanas are passed (the day is stated to begin) by their guru, (*i. e.*, the guru of the Yavanas who I suppose is no other than the often-quoted astronomical writer Yavaneśvara)." The two lines therefore contain unconnected statements, and do not in any way enable us to draw a conclusion about what Varáha Mihira considered to be the relative longitude of Lañká (or Ujjain) and Alexandria. In addition I quote a passage from some unknown writer found in the Maríchí (on Siddhánta-Siromaṇi, Gaṇitádhyáya, Madhyamádhikára, deśántara) which being apparently a periphrase of the passage from the Pañchasiddhántiká confirms the text and translation of the latter as given above:

केचिद् वारं सवितुरुदयात् प्राहुरन्ये दिनार्धात् ।
भानोरर्धास्तमयसमयादूचिरे केचिदेवम् ॥
वारास्यादिं यवननृपतिर्दिङ्मुहूर्ते निशायां ।
लाटाचार्यः कथयति पुनस्त्वार्धरात्रे स्वतन्त्रे ॥

"Some declare the day to begin from sunrise, others from noon; again others from the moment when the sun has half set. The prince of the Yavanas reckons the beginning of the day from (the moment when) ten muhúrtas of the night (are past), Láṭáchárya again in his book from midnight."

Here the "yavananṛipatiḥ" of the third line answers to the yavanaguru of Varáha Mihira and renders the identification of the latter with Yavaneśvara more probable. The statement made in the last line about Láṭáchárya is mistaken as, according to the Pañchasiddhántiká, that writer reckoned the beginning of the day from sunset, while midnight was chosen as starting-point by Áryabhaṭa.

After these preliminaries we now enter on a discussion of those passages of the Pañchasiddhántiká which contain the rules for the calculation of the mean places of the planets according to the Súrya and Romaka Siddhántas. Beginning with the former we at first extract a stanza of the 1st adhyáya which furnishes us with the requisite information about the yuga acknowledged by the Súrya Siddhánta as known to Varáha Mihira.

वर्षायुते धृतिघ्ने नववसुगुणरसरसाः स्युरधिमासाः ।
सावित्रे शरनवखेन्द्रियार्णवाशास्तिथिप्रलयाः ॥

"According to the Súrya Siddhánta there are in 180,000 years 66,389 intercalary months and 1,045,095 omitted lunar days."

Comparing these statements with those to be found on the same point in the hitherto known Súrya Siddhánta, we observe of course at once that the Pañchasiddhántiká, as was to be expected from a karaṇa-grantha, employs reduced numbers. The known Súrya Siddhánta gives the corresponding figures for a maháyuga of 4,320,000 years of which period the 180,000 years of the Pañchasiddhántiká are the twenty-fourth part. We therefore multiply the 66,389 intercalary months by 24 and find that the product 1,593,336 agrees with the figure which the Súrya Siddhánta (I. 38) gives for the intercalary months. We, however, meet with a discrepancy when comparing the two statements regarding the number of the omitted lunar days. The Súrya Siddhánta (I. 38) assumes the number of omitted lunar days in one maháyuga to be 25,082,252, while the number stated above, 1,045,095, multiplied by 24 gives as product 25,082,280, which figure exceeds the former one by 28. If we now proceed to deduce from the above statements about the nature of the yuga of the Súrya Siddhánta as known to Varáha Mihira the length of the sidereal solar year (by calculating according to the known Indian fashion the number of the tithis of the entire yuga, deducting from it the tithikshayas and dividing the remainder by the number of solar years) we obtain as the result $365^d\ 6^h\ 12'\ 36''$; while the length of the year of the known Súrya Siddhánta, in accordance with the smaller number of the omitted lunar days, amounts to a little more, *viz.*, $365^d\ 6^h\ 12'\ 36{\cdot}56''$. The discrepancy is a slight one, but it suffices to show that the Súrya Siddhánta which Varáha Mihira had before himself was different from the one known to us. It might perhaps be objected that the discrepancy is only an apparent one, Varáha Mihira having slightly changed one of the numbers of the Súrya Siddhánta in order to be able to reduce all numbers more considerably and thereby to establish more convenient rules for calculation. That the karaṇa writers are in the habit of proceeding in that manner is well-known, and we shall see later on that Varáha Mihira submits in certain cases the exact numbers to certain alterations. The present case, however, is of a different nature. The passage about the yuga of the Súrya Siddhánta is not an independent rule, in the formulation of which the writer might have allowed himself certain liberties, but a mere statement reproducing the doctrnes of another work, and as such it would be of no value whatever if it were not strictly accurate. We shall moreover meet later on with several other instances showing that the mere fact of Varáha Mihira's statements not agreeing with the known Súrya Siddhánta is not sufficient to throw a doubt on their accuracy. It is finally to be remarked that the solar year of the Súrya Siddhánta as known to Varáha Mihira is identical with the solar year of that Pauliśa Siddhánta about which Bhaṭṭotpala in his commentary on the Bṛihat Saṃhitá has given us some information (*Cf.* Colebrooke's Essays, II, p. 365).

We next turn to some verses containing rules for the calculation of the mean places of sun and moon according to the Súrya Siddhánta. They are found in the 9th adhyáya :

द्युगणे ऽर्को ऽष्टशतघ्ने विपक्षवेदार्णवे ऽर्कसिद्धान्ते ।
खरखद्विद्विनवयमोद्धृते क्रमाद् दिनदले ऽवन्त्याम्* ॥

"The (mean place of the) sun is found, for midday at Avanti, by multiplying the ahargaṇa by 800, deducting 442, and then dividing by 292,207."

This verse contains two elements which are to be considered separately; in the first place a general rule for calculating the mean place of the sun, in the second place a so-called kshepa, *i. e.*, an either additive or subtractive quantity whose introduction into the rule enables us to take for the starting-point of our calculations the epoch of the karaṇa instead of the beginning of the yuga. The general rule is understood without difficulty. It bases on the proportion: if in 65,746,575 sávana days (*i. e.*, the sávana days contained in 180,000 years), there take place 180,000 revolutions of the sun or, both numbers being reduced by 225, if 800 revolutions take place in 292,207 days, how many revolutions will take place in the given ahargaṇa ? The result is the mean place of the sun at the end of the given ahargaṇa. We now turn to the kshepa 442. If on the first Chaitra S'aka 427, which date is the starting-point of all calculations of the Pañchasiddhántiká,† the sun had performed an entire number of revolutions without remainder a kshepa would of course not be required. The actual kshepa, 442 on the other hand shows that at the mentioned time $\frac{442}{292207}$ were wanting

* Both manuscripts read in the first line ऽर्के, in the second खरखाद्विधिनव०. The second emendation is shown by calculation to be necessary. Both emendations are borne out by the manuscripts of Bhaṭṭotpala who quotes the above verse. A. reads ऽलेवत्यां B. ०लेवत्वा.

† See about this point the rule for calculating the ahargaṇa which will be discussed later on in connection with the Romaka Siddhánta.

to a complete revolution or, which comes to the same, that the sun had then performed a number of complete revolutions plus $\frac{291765}{292207}$ of a revolution. Now in order to explain this kshepa we must ascertain according to what principles and starting from which period Varáha Mihira calculated the mean place of the sun on the 1st Chaitra S'aka 427. The principles are doubtless those on which the statement concerning the nature of the yuga and the general rule for calculating the sun's mean places are founded, and we can therefore be in no uncertainty as to the method of forming the ahargaṇa and calculating from it the madhyama Súrya. Less certain is the epoch beginning from which the ahargaṇa is to be formed. If we try the different possibilities we find that neither the beginning of the Kaliyuga nor the end of the Kṛitayuga lead to the above-stated kshepa, that, however, a calculation starting from the beginning of the kalpa gives the desired result, although the course of procedure involves a few small irregularities. I will succinctly state the details of the calculation in order to facilitate its control. The sum of years (the varshagaṇa) from the beginning of the kalpa to the epoch of the karaṇa amounts to 1,955,883,606 (1,953,720,000 to the end of the kṛita, 2,160,000 for Tretá and Dvápara, 3,179 from beginning of Kali to S'aka, 427 from S'aka to epoch of Karaṇa). From the varshagaṇa we deduce in the customary manner (availing ourselves, however, of the elements of the yuga as stated by Varáha Mihira, not of the corresponding elements of the known Súrya Siddhánta) the adhimásas, which we find to amount to 721,384,203 + $\frac{178734}{180000}$. Instead of those we take, svalpántaratvát, 721,384,204 and thus obtain as the number of chándramásas for the entire stated period 24,191,987,476. Multiplying this number by 30 we get the tithis from which we deduce, by means of the statement about the tithikshayas of the yuga, the number of the ishṭa kshayáha. We find 11,356,023,206 + $\frac{4941258}{6679167}$. Instead of this we take 11,356,023,207 which deducted from the tithis gives for the ishṭa sávana ahargaṇa 7,14,403,601,073. Multiplying this number by 800, according to the general rule about the mean places of the sun, and dividing by 292,207 we find that the sun has performed, from the beginning of the kalpa down to the epoch of the Pañchasiddhántiká, 1,955,883,606 — $\frac{42}{292207}$ revolutions. The required kshepa is — $\frac{442}{292207}$. But now we have to remember that the ahargaṇa of the Súrya Siddhánta gives the mean places of the planets at midnight at

Lañka while the rule of Varáha Mihira is, as we have seen, meant to give their mean places at noon. We therefore have to deduct frcm the mean place of the sun as found hitherto his mean motion for half a day, in order to obtain his mean place on the preceding noon. This mean motion for a day is $\frac{800}{292207}$, half of which is $\frac{400}{292207}$. Combining this subtractive quantity with the one found above $\left(-\frac{42}{292207}\right)$ we get $-\frac{442}{292207}$, the exact quantity stated in Varáha Mihira's rule. The result has therefore justified the small assumptions made in the calculation of the ahargaṇa; the latter will moreover receive additional confirmation from the rules about the mean places of the moon and the planets which will be discussed later on.

The period of 800 years comprising 292,207 sávana days whereby to calculate the mean place of the sun is of frequent occurrence in Indian astronomical writings and tables. It is employed by Brahmagupta in the Khaṇḍa-khádya. It is found in the Siamese astronomical rules which became known in Europe as early as 1688 and were first interpreted by Cassini. It is likewise used in the astronomical tables sent to France by the Père Patouillet and explained by Bailly in his Traité de l'Astronomie Indienne et Orientale, (p. 54; Discours préliminaire, p. xi).

The verse which in the Pañchasiddhántiká follows next on the one explained above runs as follows:

नवशतसहस्रगुणिते खरैकपञ्चाम्बरस्वरर्तुने ।
षडूनेन्द्रियनववसुविषयजिनैर्भाजिते चन्द्रः ॥

(In the first line we have to read °स्वरर्तूने; in the second line, as will appear from the calculation, षट्शून्येन्द्रिय°; B. readsषद्यनेंद्रिय°.)

"Multiply (the ahargaṇa) by 900,000, deduct 670,217 and divide by 24,589,506; the result is the mean place of the moon." The general rule about the mean places of the moon which is contained in this verse is easily explained from the statements on the yuga of the Súrya Siddhánta which we have had occasion to consider. The yuga comprises 180,000 years. Multiplying these by 12 and adding the intercalary months we have 2,226,389 lunar synodical months. Again adding to these the 180,000 revolutions of the sun we get 2,406,389 as the number of the sidereal revolutions of the moon which take plaee in one yuga. (Dividing by the last number the sávana days of the yuga we find as the length of the sidereal month $27^d\ 7^h\ 43'\ 12{\cdot}60''$. The length of the sidereal month of the known Súrya Siddhánta amounts to $27^d\ 7^h\ 43'\ 12{\cdot}64''$). From the fact of 2,406,389 sidereal revolutions of the moon being contained in 65,746,575 days the mean place of the moon for any given ahargaṇa might of course be deduced directly; smaller numbers were, however, desirable as facilitating the calculations, and Varáha Mihira therefore substituted the relation of 900,000 revolutions to 24,589,506 days which offers the advantage of a smaller divisor, and a not only smaller but also much simpler multiplicator. The substitution involves indeed a slight inaccuracy since 900,000 revolutions of the moon take place in 24,589,506 + $\frac{746166}{2406389}$ days, the fractional part of which quantity is neglected in the general rule. The error which results therefrom is, although insignificant, not to remain uncorrected and Varáha Mihira adds therefore (after one intervening verse about the mean place of the moon's uchcha) the following rule:

शशिविषयघ्नानीन्दोः खार्काग्निहृतानि मण्डलानि ऋणम् ।
स्वोच्चे दिग्घ्नानि धनं खरदस्वयमोद्धृते विकलाः ॥

"Multiply the (elapsed) revolutions of the moon by 51 and divide by 3,120; the (resulting) seconds are to be deducted (from the mean place of the moon as found by the general rule)." (The second part of the rule refers to the moon's uchcha). The correction stated here is easily accounted for. By a proportional calculation we find that the moon performs in $\frac{746166}{2406389}$ of a day about 14,708 seconds of a circle. To so much consequently the error resulting from the neglect of the fraction amounts for 900,000 revolutions. The error for one revolution is therefore equal to $\frac{14708}{900000}$ seconds or, as Varáha Mihira prefers to express it, reducing both numbers by 288, to (about) $\frac{51}{3120}$ seconds. The explanation of the kshepa, 670,217 is not quite so simple as that of the solar kshepa. We of course again employ the kalpády-ahargaṇa which had led to a satisfactory result in the case of the sun's mean place. If we, however, proceed according to the general rule given by Varáha Mihira, multiplying that ahargaṇa by 900,000 and dividing by 24,589,506 and finally applying the prescribed correction, we find that the remainder combined with the moon's mean motion for half a day does not equal the stated kshepa. The fact is that approximately correct rules and approximately accurate corrections are applicable to comparatively short periods, but become altogether misleading if periods of very considerable length as for instance the kalpády-ahargaṇa are concerned. In such cases we must discontinue the use of reduced factors and employ absolutely correct numbers. In the present instance we consequently have to employ the number of lunar months and sávana days of the entire yuga. We multiply the kalpády-ahargaṇa as formed above by 2,406,389 (= the number of the sidereal revolutions of the moon in a yuga), divide by 65,746,575 (= number of sávana days), reject the quotient which expresses the complete revolutions and keep the remainder 65,157,822 which indicates that at the time of the epoch the moon had, in addition to the complete revolutions, performed $\frac{65157822}{65746575}$ of a revolution or, which is the same, that $\frac{588753}{65746575}$ were wanting to a complete revolution. This fraction, in order to be capable of being introduced into the general rule must be turned into 24,589,506$^{\text{ths}}$; which being done we obtain $\frac{220197}{24589506}$. To this quantity again we have to add half the amount of the moon's daily mean motion $= \frac{450000}{24589506}$ in order to find the mean place of the moon at noon instead of the following midnight. The addition of the two subtractive quantities gives — 670,197, which quantity differs by 20 only from the kshepa stated in Varáha Mihira's rule: the discrepancy to whatever reasons it may be owing is much too small to be taken into account; the difference in the mean place of the moon at the time of the epoch which results from it amounts to 1″ 3‴ only.

The rule following next on the one referring to the mean motion of the moon teaches how to find the mean place of the moon's uchcha. A few unimportant emendations being made, it runs as follows:

नवशतगुणिते दद्याद्रसविषयगुणाम्बरर्तुयमपक्षान् ।
नववसुसप्ताष्टाम्बरनवाश्विभक्ते शशाङ्कोच्चम् ॥

"Add 2,260,356 to (the ahargaṇa) multiplied by 900 and divide by 2,908,789; the result is the mean place of the uchcha of the moon."

From the general rule involved in the above viz. that 900 revolutions of the moon's uchcha take place in 2,908,789 days, it follows that one revolution occupies 3,231^{d} 23^{h} 42′ 16·76″. Comparing this period with the duration of the revolution according to the known Súrya Siddhánta which amounts to 3,232^{d} 2^{h} 14′ 53·4″ we feel at once inclined to suspect that the difference of the two quantities which is rather considerable is not merely owing to Varáha Mihira's desire of establishing a rule offering facilities for practical calculations but results from a real discrepancy of the two Súrya Siddhántas. And a closer consideration of the point confirms this suspicion. According to the known Súrya Siddhánta the chandrochcha of the moon performs 488,203 resolutions in one maháyuga If we now, in order to ascertain the corresponding number of the

Súrya Siddhánta known to Varáha Mihira, multiply the 1,577,917,800 days of the maháyuga by 900 and divide by 2,908,789 we get as quotient nearly 488,219. Varáha Mihira's Súrya Siddhánta therefore reckoned so many revolutions of the uchcha to one maháyuga and it is of interest to remark that it therein exactly agreed with the doctrine of A'ryabhaṭa (see the A'ryabhaṭíya edited by Kern, p. 6). We finally test the exactness of our assumption by the calculation of the kshepa stated in Varáha Mihira's rule. Multiplying the kalpády-ahargaṇa as ascertained before by 488,219 and dividing the product by 1,577,917,800 (the number of the days of a yuga) we get as remainder $\frac{1226408787}{1577917800}$. Converting the quantity which expresses the fraction of the revolution incomplete at the epoch of the karaṇa into 2,908,789ths in order to render it capable of being introduced into the general rule, we obtain for the numerator 2260805 (and a small fraction). From this positive kshepa we finally deduct 450 = half the daily motion of the uchcha in order to carry back the mean place to the preceding noon ; the remainder 2,260,357 differs by one only from the kshepa stated in the rule. It thus appears that the number we had assumed for the revolutions of the uchcha according to Varáha Mihira's Súrya Siddhánta is the right one. Varáha Mihira finally applies a correction which becomes necessary in consequence of reduced and slightly inaccurate figures having been employed in the general rule. The amount of this correction is stated in the second half of the verse quoted above शशिविषयघ्नानीन्दोः etc., I am, however, unable for the present to account for it by calculation. The fault possibly lies with the corruption of the manuscripts.

The same chapter contains a rule for calculating the mean places of the moon's node ; which I am, however, unable to explain. We therefore turn now to the 16th adhyáya which treats of the mean places of the so-called tárá-grahas. The text of this short adhyáya runs as follows :

एष निशार्धेऽवन्त्यां ताराग्रहनिर्णयोऽर्कसिद्धान्ते । *
तत्रेन्दुपुत्रशुक्रौ तुल्यगतौ मध्यमार्केण । †
जीवस्य शताभ्यस्तं द्विचियमाग्निचिसागरैर्विभजेत् । ‡
द्युगणं कुजस्य चन्द्राहतं तु सप्ताष्टषड्घ्नत्तम् । §
सौरस्य सहस्रगुणाद्दतुरसशून्यर्तुषट्कमुनिखेकैः । ||

* A. B. ॰वत्यां A. निर्णोर्कसि॰ B. ॰ग्रहणकसि॰

† A. मह्मा॰ B. ॰मार्केसा.

‡ B. निवस्य.

§ A. सप्ताष्टघ्नत्तं.

|| B. सौम्यस्य A. गुणाद्दनुरसस्रू॰

यल्लब्धं तेभगणाः शेषा मध्यग्रहाः क्रमेणैव । *
दश दश भगणे भगणे संशोध्यास्तत्पराः सुरेज्यस्य । †
मनवः कुजस्य देयाः शनेश्च वाणा विशोध्यास्तु । ‡
राशिचतुष्टयमंशद्वयं कलाविंशतिर्वसुसमेताः । §
नववेदाश्च विलिप्ताः शनेर्धने मध्यमास्येव (?) ।
अष्टौ भागा लिप्तर्तवः खमत्यौ गुरौ विलिप्ताश्च । ¶
क्षेपः कुजस्य यमतिथिपञ्चत्रिंशच्च राश्याद्याः । **
शतगुणिते बुधशीघ्रं खरनवसप्ताष्टभाजिते क्रमशः । ††
अत्रार्धपञ्चमास्तत्पराश्च भगणाहताः क्षेपः । ‡‡
शितशीघ्रं दशगुणिते द्युगणे भक्ते खरार्णवाश्वियमैः । §§
अर्धैकादश देया विलिप्ता भगणसंगुणिताः । ||||
सिंहस्य वसुयमांशाः खरेन्दवो लिप्तिका ज्ञशीघ्रधनम् । ¶¶
शोध्याः सितस्य विकलाः शशिरसनवपञ्चगुणदहनाः । ***

(The few remaining verses of the adhyáya will be quoted below.)

"1. The determination of the (mean places of the) smaller planets (*i. e.*, the grahas except sun and moon) for midnight at Avanti is as follows:

"2. Mercury and Venus have the same motion with the mean sun.

"3. For Jupiter multiply the ahargaṇa by 100 and divide by 433,232.

"4. For Mars multiply the ahargaṇa by 1 and divide by 687.

"5. For Saturn multiply the ahargaṇa by 1000 and divide by 10,766,066.

"6. The quotients are the entire revolutions, the remainders are the mean places of the planets in their order.

"7. For each revolution of Jupiter 10 tatparas (thirds, *i. e.*, sixtieth parts of a second) are to be deducted.

"8. 14 tatparas are to be added for each revolution of Mars; 5 are to be deducted for each revolution of Saturn.

"9. 10. 4 signs, 2 degrees, 28 minutes and 49 seconds are to be added to the mean place of Saturn.

"11. 8 degrees, 6 minutes and 20 seconds are the additive quantity for Jupiter.

* B. सहस्रगुणा १००० । ऋतुरस०
† B. दशांशभगणे.
‡ B. नमवः कुकुचु दे० A. ०शोध्यास्तु
§ B. ०शोध्याः स्युः
|| B. नवदेवाश्च लिप्ताः शनेमध्यमस्त्वेयम्.
¶ B. ०र्तवः शेषसौ गुरुवि०
** A. जमति० B. तितिथि० ०शच्च.
†† B. ०णितं.
‡‡ A. ०हतः B. हताच्चिपा.
§§ A. B. द्विगुणे.
|||| A. अर्कैका० B. ०लिप्तिका भ०
¶¶ A. खरोदवो B. खरेदेवो.
*** A. B. शोसितस्य ०पञ्चा० ०गणा०

"12. For Mars the additive quantity are 2 signs, 15 degrees, 35 minutes.

"13. For the S'ighra of Mercury, multiply the ahargaṇa by 100 and divide by 8,797.

"14. There the kshepa amounts to the product of four and a half tatparas into the (accomplished) revolutions.

"15. For the S'ighra of Venus multiply the ahargaṇa by 10 and divide by 2,247.

"16. To be added are ten and a half seconds multiplied by the revolutions.

"17. 28 degrees of Leo (*i. e.*, 4 signs plus 28 degrees) and 17 minutes are the additive quantity of the S'ighra of Budha.

"18. From (the S'ighra of) Venus are to be deducted 332,961 seconds."

Of these sixteen lines, lines 1 to 6 contain rules for the calculation of the mean places of the five planets. Lines 7 and 8 state what corrections have to be applied to the mean places of Jupiter, Mars and Saturn if calculated according to the rules previously laid down. Lines 9 to 12 inform us what quantities are to be added to the mean places calculated and corrected according to the preceding rules, *i. e.*, they state the mean longitudes of the planets at the epoch of the Karaṇa. Lines 13 to 16 contain the rules for calculating and correcting the mean places of the S'ighra of Mercury and Venus.

Let us now enter into details and compare the above statement regarding the planets' periods of revolution with what is known from other sources. Of Jupiter it is stated in line 3 that it performs 100 revolutions in 433,232 days; one revolution therefore occupies 4,332·32 days. This nearly agrees with the doctrine of the published Súrya Siddhánta which counts 364,220 revolutions of Jupiter to 1 maháyuga of 4,320,000 years, and consequently, the maháyuga comprising 1,577,917,828 days, 1 revolution to 4,332·3,206,523 days. A small difference between Jupiter's periods of revolution according to the known Súrya Siddhánta and the Súrya Siddhánta of the Pañchasiddhántiká results of course from the repeatedly mentioned fact of the yuga of the latter work comprising 28 days less. We therefore assume at first that the Súrya Siddhánta of the Pañchasiddhántiká also gave 364,220 revolutions to 1 yuga, and therefrom derive the exact period of one revolution $\frac{1577917800}{364200} = 4{,}332{\cdot}3{,}205{,}754$. From this it appears that the general rule given above, according to which 1 revolution comprises 4,332·32 days, is inaccurate and stands in need of a correction. In order to ascertain the amount of the latter we take the difference of the accurate and the approximate periods of revolution = 0·0005754 and therefrom derive by means of a proportion (4,332·3,205,754 : 360 = 0·0005754 : ♓) that fractional part of a circle which Jupiter passes through in the 0·0005754th of a day. The result are 10‴ of a circle. Thereby is explained the rule given in line 7 according to which 10‴ for each revolution have to be deducted from the mean place of Jupiter resulting from line 3. We finally have to explain the kshepa stated in line 11. Multiplying the kalpády-ahargaṇa by 364, 220 and dividing by the days of a maháyuga we find that from the beginning of the kalpa down to the epoch of the book, Jupiter had performed $16490909 + \frac{1776393}{78895890}$ revolutions. The fraction turned into degrees, minutes etc. gives 8° 6′ 20″ for the mean longitude of Jupiter at the time of the epoch. As according to line 1, the rules for the mean longitudes of the planets refer to midnight at Avanti, the deduction of half a day's mean motion which had to be made in the case of sun, moon and moon's apsis is not required here.

We next turn to Mars. According to line 4, 1 revolution of Mars takes place in 687 days. The round number clearly shows the rule to be only an approximate one, and it now becomes our task to ascertain the exact determination on which it is founded. According to the published Súrya Siddhánta, Mars performs 1 revolution in 686·99,749,394 days, and it so might appear that the approximate value 687 presupposes the more accurate value 686·9,974... (if we neglect for the moment the small difference resulting from the slightly different number of the days of a yuga according to the two Súrya Siddhántas) and that consequently the Súrya Siddhánta of the Pañchasiddhántiká, as well as the known Súrya Siddhánta counts 2,296,832 revolutions of Mars to 1 maháyuga. But if on this assumption we try to explain the correction of Mars' mean place which is stated in line 8 and the kshepa mentioned in line 12, we are unsuccessful and conclude therefrom that our assumption has been premature. We therefore try the opposite course and proceed to deduce the number of revolutions which Mars performs in one yuga from the correction of fourteen tatparas for each revolution. If Mars, as the general rule teaches, performs 360° in 687 days, it passes through 14‴ in 0·000124 ... of a day. This fraction has therefore to be deducted from the approximate period of revolution, 687 days, when the remainder, 686·999874 ... days, indicates the accurate period of revolution. By this again we divide the days of the yuga (1,577,917,800). The quotient, 2,296,824, indicates that according to the Súrya Siddhánta of the Pañchasiddhántiká, Mars performs in one yuga 2,296,824 revolutions; which number agrees with that given in the A'ryabhaṭíya, (p. 4) and likewise in the Pauliśa Siddhánta (Colebrooke's Essays, II, p. 365). This number finally explains the kshepa stated in line 12; for if we multiply by it the kalpády-ahargaṇa and divide by the number of the days of a yuga, the remainder, which indicates the mean longitude of Mars at the time of the epoch, is 2^s 15° 35′.

Passing on to Saturn we find it stated in line 5 that 1000 revolutions of the planet occupy 10,766,066 days. One revolution therefore occupies 10766·066 days. The difference of this value from the corresponding value which results from the statements of the known Súrya Siddhánta, *viz.*, 10765·77307461, is too considerable for us to assume that the Súrya Siddhánta of the Pañchasiddhántiká should have agreed with the known Súrya Siddhánta in reckoning 146,568 revolutions of Saturn to 1 maháyuga. In order to find the number of revolutions actually acknowledged by the former work we therefore again have recourse to the correction of Saturn's mean longitude. As according to the latter (see line 8) 5″ have to be deducted for each revolution of Saturn, the period assumed for Saturn's revolution in the general rule is too short and has to be lengthened by the time which Saturn requires to pass through 5‴ of a circle. That time amounts to 0·0007 ... of a day. This being added to 10766·066 and the days of a yuga being divided by the sum, 10766·0667, the quotient, 146,564, indicates the number of revolutions in one yuga. This result shows that here too the Súrya Siddhánta referred to by Varáha Mihira agreed with the Áryabhaṭíya and the Pauliśa Siddhánta while it differed from the known Súrya Siddhánta. Finally in order to explain the kshepa we multiply the kalpády-ahargaṇa by 146,564 and divide the product by the days of a yuga. The result—4^s 2° 28′ 49″—indicates the mean longitude of Saturn at the time of the epoch in strict agreement with line 9.

We now turn to Mercury and Venus whose periods of revolution are treated in the Indian systems as revolutions of their śíghras while the mean place of the two planets is supposed always to correspond to the mean place of the sun. The latter circumstance is mentioned in line 2. Lines 9 and 10 state the real period of revolution of Mercury and the rule for finding its mean longitude. A hundred revolutions are reckoned to 8,797 days; one revolution therefore occupies 87·97 days. The known Súrya Siddhánta gives to one yuga 17,937,060 revolutions of Mercury; to one of the latter therefore 87·969702 days. So far it might appear that the two Siddhántas agree with regard to the number of revolutions of Mercury; this supposition, however, does not confirm itself when we make use of the correction stated in line 14 for the purpose of deducing therefrom the number of Mercury's revolutions in one yuga. We find by proportion that Mercury takes 0·000005 of a day to pass through 4·5‴ of a circle; we therefore subtract the fraction from 87·97 and divide by the remainder the days of a yuga, when the quotient, 1,793,700, indicates the number of Mercury's revolutions. This number agrees neither with the one stated in the known Súrya Siddhánta (17,937,060) nor with the doctrine of A'ryabhaṭa who reckons 17,937,020 revolutions of Mercury to one yuga (A'ryabhaṭa, p. 6) ; on the other hand it does not differ from the number assumed in the Pauliśa Siddhánta (Colebrooke, Essays, II, p. 365). Mercury's kshepa finally is stated in line 17. We multiply the kalpády-ahargaṇa by 17,937,000 and divide by the days of a yuga. The result is 148° 17′ and about 6″; the last quantity is not stated by Varáha Mihira.

We conclude with Venus. According to line 15 it performs ten revolutions in 2,247 days, consequently one revolution in 224·7 days. According to line 16 we have to add 10·5″ for each revolution to the mean place of Venus as calculated in line 15. Venus passes through so many seconds in 0·00182 of a day. We deduct this amount from 224·7 and divide by the remainder the days of the yuga. The quotient, 7,022,388, indicates the number of revolutions that Venus performs in one yuga, a number in which the Súrya Siddhánta of the Pañchasiddhántiká again agrees with the A'ryabhaṭíya (p. 6) and the Pauliśa Siddhánta, while the known Súrya Siddhánta reckons 7,022,376 revolutions of Venus to one yuga. Lastly to calculate the kshepa we multiply the kalpády-ahargaṇa by 7,022,388 and divide by the days of a yuga. The result is 8^s 27° 30′ 35″, which positive quantity is turned into a negative one by being deducted from an entire revolution or twelve signs. The remainder is 3^s 2° 29′ 25″ which quantity is equal to 332,965 seconds. The text says 332,961 ; but most probably we have to read (in line 18) शर instead of शशि, which emendation would remove the discrepancy.

In addition to the rules translated and explained in the above the chapter on " Súrya Siddhánta, madhyagati " contains a few more verses which as it appears state a so-called bíja to be applied to the positions of the planets resulting from the general rules. These verses, which together with those already quoted constitute the entire chapter, run as follows :

क्षेप्याः स्वरेन्दुविकलाः प्रतिवर्षं* मध्यमक्षितिजे† ।
दश दश गुरोर्विशोध्याः शनैश्वरे सार्धसप्त युताः ॥
पञ्चाब्धयो‡ विशोध्याः सिते बुधे खाश्विचन्द्रयुताः§ ।
खखवेदेन्दुविकालिकाः शोध्याः सुरपूजितस्य मध्यात् स्युः ॥

" Seventeen seconds for each year are to be added to the mean place of Mars ; ten to be deducted from that of Jupiter ; seven and a half to be

* A. B. ०वषमाध्य०

† A. ०जो B. जोः

‡ A. पंचाद्वयो B. पंचद्वयो.

§ A. स्ताश्वि० ०युताः

added to that of Saturn; forty-five to be deducted from that of Venus; one hundred and twenty to be added to that of Mercury. Fourteen hundred seconds are to be deducted from the mean place of Jupiter."

These corrections call for no special remarks. As in similar cases, no special reason is given for the amount of the correction, it being understood that corrections of just that value will bring about a satisfactory agreement between calculation and observation. It is not said with whom the bíja originated; but we have no reason to doubt that it was Varáha Mihira himself who had perceived that the elements of the Súrya Siddhánta did not fully satisfy the requirements of his time. It is moreover noteworthy that the corrections proposed by Varáha Mihira for the Súrya Siddhánta do not differ very much from those proposed for the elements of the A'ryabhaṭíya by Lallácharya who is called the disciple of A'ryabhaṭa. The passage from Lalla which refers to this point is quoted in the commentary on the A'ryabhaṭíya (Kern's edition, p. 58) and runs as follows:

शाके नखाब्धिरहिते शशिनोऽब्दखैस्तत्तुङ्गतः कृतशिवैस्तमसष्षडङ्कैः ।
शैलाब्धिभिस्सुरगुरोर्गुणिते सितोच्चाच्छोध्यं त्रिपञ्चकुहते ऽभ्रशराद्विभक्ते ॥
स्वम्बेरमाम्बुधिहते क्षितिनन्दनस्य सूर्यात्मजस्य गुणिते ऽम्बरलोचनैश्च ।
व्योमाग्निवेदनिहते विदधीत लब्धं शीतांशुसूनुकुजमन्दकलासु वृद्धिम् ॥

"Deduct 420 from the S'áka year, multiply it, for the moon, by 25, for the moon's uchcha by 114, for Ráhu by 96, for Jupiter by 47, for Venus' uchcha by 153, for Mars by 48, for Saturn by 20 and (for Mercury's uchcha) by 430; divide in all cases by 250. The resulting (minutes) are to be added to the minutes (of the mean places) of Mercury, Mars and Saturn (while they are to be deducted in the case of the other planets)."

This means that—the moon with her apogee and node being left aside—$\frac{47'}{250}$ = about 11″ for each year are to be deducted from Jupiter's mean place; $\frac{53'}{250} = 36''$ are to be deducted from the mean place of Venus; $\frac{430'}{250} = 103''$ are to be added to Mercury; $\frac{48'}{250} = 11''$ are to be added to Mars; $\frac{20'}{250} = 5''$ are to be added to Saturn. It will be observed that these corrections differ in no case very widely, in some hardly at all from those which Varáha Mihira proposes.

The last clause in Varáha Mihira's chapter on the mean motions of the planets according to which 1,400 seconds are to be deducted from the mean place of Jupiter must refer to a constant bíja to be applied to the place of the planet at the epoch of the Karaṇa. It is too considerable for being considered as a yearly bíja; a bíja of the latter kind for Jupiter has moreover been stated in the preceding verse already.

Having gathered all the information which the Pañchasiddhántiká supplies regarding the mean motions of the planets according to the Súrya Siddhánta we now turn to the Romaka Siddhánta.

The information regarding the yuga adopted by the Romaka Siddhánta is contained in the 15th verse of the first adhyáya:

रोमकयुगमर्केन्द्वोर्वर्षाण्याकाशपञ्चवसुपक्षाः ।
खेन्द्रियदिशोऽधिमासाः स्वरकृतविषयाष्टयः* प्रलयाः ॥

"The lunisolar yuga of the Romaka (Siddhánta) comprises 2,850 years; (in these) there are 1,050 adhimásas and 16,547 omitted lunar days."

The first point to be noted with regard to this passage is that the yuga is called "arkendvoḥ," a lunisolar yuga, from which it might appear that the yuga of the Romaka Siddhánta comprised an integral number of revolutions of the sun and the moon only, while the yugas of the other Siddhántas as for instance the Súrya Siddhánta are founded on the revolutions of the other planets also. If this was really the case cannot as yet be settled with certainty. The Pañchasiddhántiká indeed extracts from the Romaka Siddhánta information about the motions of the sun and moon merely; but on the other hand a passage in the Brahmagupta Sphuṭa Siddhánta which will be quoted later on shows that S'rísheṇa treated also of the other planets. That he, however, in the construction of his astronomical periods considerably diverged from the other Siddhántas we are told by Brahmagupta himself in a passage occurring in the first chapter of his Sphuṭa Siddhánta:

युगमन्वन्तरकल्पाः कालपरिच्छेदकाः स्मृतावुक्ताः ।
यस्मान्न रोमके ते स्मृतिबाह्यो रोमकस्तस्मात् ॥

"Because the yugas, manvantaras and kalpas which are stated in the Smṛitis as defining time are not employed in the Romaka (Siddhánta), therefore the Romaka stands outside Smṛiti."

If we now inquire more closely into the nature of the period made use of in the Romaka Siddhánta, we observe at once that the number of the solar years as well as that of the intercalary months can be reduced by 150 so that we may say as well that 19 solar years contain 7 intercalary months or that 19 solar years contain 235 synodical months. In other words the yuga of the Romaka Siddhánta is founded on the well-known Metonic period. Nor is it a matter of great difficulty to

* A. स्वकृत० ०ष्टयाप्रल०

find out why the Romaka uses instead of the simple Metonic period its 150th multiple. At first we have to ascertain the length of the solar year of the Romaka, by dividing the 1,040,953 civil days comprised in the entire yuga by 2,850, the number of years; when we obtain $365^d\ 5^h\ 55'\ 12''$; a result showing, as of course we might already have inferred from the mere use of the Metonic period, that the Romaka uses not the sidereal solar year the uniform employment of which is so marked a feature of later Indian astronomy but the tropical solar year. Nor again is there any room for doubt concerning the origin of this determination of the solar year. It is the tropical year of Hipparchus or if we like of Ptolemy who adopted his great predecessor's estimation of the time occupied by one tropical revolution of the sun without attempting to correct it although it is considerably too long. (*Cf.* Ptolemy's Syntaxis, Book III.)

It is certainly a matter of interest to meet in one of the oldest Siddhántas with an estimation of the year's length whose Greek origin it is impossible to deny. The comparison of the length of the year as fixed by the different Siddhántas on one side and the Greek astronomers on the other side is generally beset by considerable difficulties chiefly in consequence of the Hindú astronomers giving no direct information about the length of the tropical year, while the Greeks on their part speak in clear terms of the tropical year only, and oblige us to infer their opinions regarding the length of the sidereal year. It is of course easy enough to deduce the length of the one species of year from the length of the other if we are acquainted with the assumed yearly rate of the precession of the equinoxes. But it so happens that the determination of the latter point is in many cases by no means easy. To take for instance the (published) Súrya Siddhánta we easily derive from its data the length of its sidereal year, *viz.*, $365^d\ 6^h\ 12^m\ 36{\cdot}6^s$ and, if we avail ourselves of the amount of yearly precession as stated in its tripraśnádhyáya, *viz.*, $54''$, we find for the length of the tropical year $365^d\ 5^h\ 50^m\ 41{\cdot}7^s$, which is a determination much more correct then that of the Greek astronomers. But I quite share the suspicion expressed by Professor Whitney (translation of the Súrya Siddhánta, p. 246 ff.) that the passage of the tripraśnádhikára alluded to formed no part of the original Súrya Siddhánta, but is a later interpolation. It remains therefore uncertain by what process the length of the sidereal year of the Súrya Siddhánta was determined; the possibility of its being founded on the tropical year of Hipparchus and the Romaka Siddhánta is meanwhile not to be considered as altogether excluded.*

* The proposal made by Biot (Etudes sur l' astronomie Indienne, p. 29) to account for the sidereal year of the Súrya Siddhánta by considering it as the

Hipparchus himself basing on his calculation of the tropical year and on the Metonic cycle constructed a period of 304 (4 × 4 × 19) years *minus* one day = 111,035 days which period comprises 3,760 synodical months. (See Ideler's Chronology, I, p. 352.) The advantages of this period are that it comprises integral numbers of civil days and of lunar months and, very nearly, of tropical years while at the same time it implies nearly accurate estimations of the length of the year and the month, (*viz.*, $365^d\ 5^h\ 55'\ 15''$ and $29^d\ 12^h\ 44'\ 2{\cdot}5''$; the accurate figures according to Hipparchus being $365^d\ 5^h\ 55'\ 12''$ and $29^d\ 12^h\ 44'\ 3{\cdot}2''$). A period of this kind would, however, apparently not have suited Indian purposes. We here are met by one of the particular Indian requirements which helped to transform systems of Greek origin into the Indian systems with their strongly marked peculiarities. At the time when Greek astronomy began to act on India the calendar in prevalent use in the latter country was undoubtedly already the well-known lunisolar one with its tithis and intercalary lunar months. The peculiarity of this calendar is, that it does not inform one directly of the number of civil days which have expired from the beginning of the current year but only of the number of the elapsed lunar days or tithis. From the latter the number of civil days has to be derived by means of a proportion. And again in order to ascertain the number of tithis contained in a certain number of years antecedent to the current year, it is necessary at first to ascertain the number of intercalary lunar months which have occurred in the course of those years, a process requiring the employment of another proportion. We cannot enter in this place into a discussion of the reasons which may have led to the adoption of such an extraordinary and inconvenient style of calendar; for our purposes it is sufficient to know that it had established itself on Indian soil at an early period. It appears for instance in the Jyotisha-Vedáñga, although the form in which it there presents itself is a comparatively simple and primitive one, the writer of the Vedáñga neither having an accurate knowledge of the length of the revolutions of the sun and the moon nor being acquainted with the solar and lunar inequalities. At any rate it had taken a firm hold on the Hindú nation and when Greek notions and methods streamed in, they had to adapt themselves to the existing system. Thus the above described manner of calculating the number of civil days comprised in a certain period with its twofold transformation of solar years into lunar months and of lunar days into civil days required the establishment of

arithmetical mean taken between the sidereal year of Hipparchus and that of the Chaldeans has not much to recommend itself; the mean would not even be an accurate one.

periods containing integral numbers of all the different constituent elements, as otherwise the already laborious calculations would have become vastly more troublesome. For this reason the author of the Romaka Siddhánta formed his yuga of 2,850 years which is not only a multiple of 19 years, from which circumstance it follows that it comprises an integral number of intercalary months; but which in addition comprises as we have seen an integral number of civil days. That 150 is the smallest multiplier by which the desired purpose can be effected it is easy to see. The Romaka period has the additional advantage of being based on the exact tropical year of Hipparchus while the period of 304 years demands a lengthening of the year by 3 seconds.

From the verse translated above we moreover derive the length of the month according to the Romaka Siddhánta. Dividing the sávana days of the yuga by the number of its synodical months we obtain for the length of one synodical month $29^d\ 12^h\ 44'\ 2{\cdot}25''$. Further, adding to the number of the synodical months of the yuga the number of solar revolutions and dividing by the sum the number of sávana days, we arrive at a periodical month of $27^d\ 7^h\ 43'\ 6{\cdot}3''$. (It need not be mentioned that the periodical month of the Romaka is, like its year, a tropical one.) A comparison of these values with those assigned to the same periods by the Greek astronomers offers, owing to the particular nature of the case, no special interest. Hipparchus had found for the length of the synodical month $29^d\ 12^h\ 44'\ 3{\cdot}262''$* and this estimation might not improbably have been known to the author of the Romaka Siddhánta; but since, as we have seen above, the absolute equality of 19 solar years and 235 synodical months was insisted on, the length of the month had to be modified slightly.†

* This is the value resulting from Hipparchus's lunisolar period (about which see the following note). Ptolemy, as pointed out by Biot, Résumé de Chronologie Astronomique, p. 401, derives his value of the synodical month from the same period, arrives, however, from unknown reasons at a result differing in the decimal places of the seconds ($29^d\ 12^h\ 44'\ 3{\cdot}333''$) and employs this value in all his subsequent investigations.

† The above remark on the synodical month of course applies to the periodical month likewise. Although, however, I do not wish to enter in this place into a detailed comparison of the Greek and Indian determinations of the length of the month the following hints as to the course of procedure of the chief Greek astronomers may find a place. The lunisolar period employed by Hipparchus and described by Ptolemy in the 2nd chapter of the 4th book of the Syntaxis sets 126,007 days *plus* one hour equal on one side to 4,267 synodical months and on the other side to 4,612 sidereal revolutions of the moon *minus* $7\frac{1}{2}°$; the same period is said to comprise 345 sidereal revolutions of the sun *minus* $7\frac{1}{2}°$. On these equalities may be based in the first place a calculation of the length of the synodical month, in the second place

We now proceed to consider some verses which teach how to employ the general principles stated above for the purpose of calculating the mean places of sun and moon. They are found in the 8th adhyáya whose general subject is the calculation of solar eclipses according to the Romaka:

रोमकसूर्यो द्युगणात् खतिथिघ्नात् पञ्चकर्तुपरिहीणात् ।
सप्ताष्टकसप्तकृतेन्द्रियोद्धृतान्मध्यमाः क्रमशः ॥

(Without entering on the discussion of a few necessary emendations of the above text I at once proceed to render its undoubted sense.) "Multiply the ahargaṇa by 150, subtract from it 65 and divide by 54,787; the result is the mean place of the sun according to the Romaka." (From one of the following verses we see that the mean places of the Romaka are calculated for the time of sunset at Avanti.) I wish, with regard to the above verse as well as those verses which will be translated later on, to confine myself to the general part of the rule and not to enter for the present on a discussion of the additive quantity—the kshepa—which as we have seen when considering the corresponding rules of the Súrya Siddhánta is introduced for the purpose of enabling us to start in our calculations from the epoch of the karaṇa. The additive—or in this case subtractive—quantity (—65) being left aside the remainder of the rule presents no difficulties. As we have seen above the

a calculation, independent from the former one, of the length of the sidereal month and the sidereal year. Ptolemy when determining the mean motions of the moon exclusively avails himself of the first mentioned equation between 126,007 days *plus* one hour and 4,267 synodical months and—employing the mean tropical motion of the sun settled independently—derives therefrom the mean tropical motion of the moon. From the latter it is easy to calculate the length of the periodical (tropical) month, with the result $27^d\ 7^h\ 43'\ 7{\cdot}27''$, and from that again, if we avail ourselves of the value of the yearly precession which Ptolemy had accepted, *viz.*, 36″, the value of the sidereal month, for which we find $27^d\ 7^h\ 43'\ 12{\cdot}1''$. (Thus also in the Comparative Table of the sidereal revolutions of the planets, Burgess—Whitney's translation of the Súrya Siddhánta, p. 168.) Hipparchus on the other hand who had not settled a definite value of the annual precession would, in order to ascertain the duration of the sidereal month, most probably have made use of the second of the above-mentioned equations. The resulting length of the sidereal month is $27^d\ 7^h\ 43'\ 13{\cdot}57''$ (thus also Biot études sur l' astronomie Indienne, p. 44). A certain rate of the precession may be derived from comparing this sidereal month with the tropical month mentioned above (regarding whose length Ptolemy and Hipparchus agree if we set aside aside the insignificant difference resulting from the inadvertence of Ptolemy remarked on in the preceding note). Or again the rate of the precession may be calculated by comparing the length of the sidereal year which results from the third of the stated equations (*vide* $365^d\ 6^h\ 14'\ 11{\cdot}79''$) with the duration of the tropical year; we thus obtain for the annual rate 46·8″.

sun performs 2,850 revolutions in 1,040,953 days. Both numbers can be reduced by 19. In order therefore to find the place of the sun at a given time or, in Indian terminology, for a given ahargaṇa, we multiply the ahargaṇa by 150 and divide the product by 54,787. The result represents the mean place of the sun in the tropical sphere.

In the same adhyáya we read the following rule for calculating the mean place of the moon :

खखरूपाष्टगुणाष्टघ्नात्कृताष्टनवकैकवर्जिताद् द्युगणात् ।
त्रिविषवेचखक्षताशापरिशुद्धान्मध्यमशीतांशोः ॥

(The translation will show what emendations of the text are required.) "Multiply the ahargaṇa by 38,100, subtract 1,984 and divide by 1,040,953 ; the result is the mean place of the moon."

The kshepa being set aside the rule is easy to understand. The multiplier is the number of the sidereal months contained in the yuga of the Romaka Siddhánta ; the number of the civil days of the same period forms the divisor. The quotient represents the mean place of the moon in the tropical sphere.

While the preceding rules regarding the mean places of sun and moon gave no information about the elements of the Romaka which we might not have directly derived from the statement concerning the nature of the yuga and were chiefly interesting as confirming the latter, a new element is furnished by the next following verse which refers to the anomaly of the moon :

शून्यैकैकाभ्यस्तान् नवशून्यरसान्विताद्दिनसमूहात् ।
रूपत्रिखगुणभक्तात् केन्द्रं शशिनो ऽस्तगमे ऽवन्त्याम् ॥

(Without translating the compound which refers to the kshepa, and only remarking that the last words are an emendation of शशिनोस्तगमवद्यां which is the reading exhibited by the manuscripts we render :) "Multiply the ahargaṇa by 110 and divide by 3,031 ; the result is the moon's kendra at the time of sunset at Avanti."

The last words indicate the time of the day from which the calculations according to the Romaka Siddhánta have to start and the Meridian employed ; they will not be considered here as they are important only if viewed in connexion with the kshepa. The kendra performing 110 revolutions in 3,031 days we obtain by division $27^{d}\ 13^{h}\ 18'\ 32{\cdot}7''$ as the time of one revolution of the kendra or, according to the Greeks' and our own terminology, of one anomalistic month. The manner in which we are here taught to calculate the moon's mean anomaly seems to be another interesting proof of the Romaka Siddhánta standing in a specially close relation to Greek astronomy. The Indian systems in general do, as is well-known, not speak of revolutions of the moon's anomaly but of revolutions of the uchcha, *i. e.*, the apogee or the apsis, while the Greeks combined the motion of the apogee and that of the moon herself in the so-called restitution of the anomaly (ἀποκατάστασις τῆς ἀνωμαλίας) which corresponds to the modern anomalistic month and which we here meet with in the Romaka as the revolution of the kendra. I am aware that Hindu Astronomers occasionally calculate the position of the kendra in the same way, *i. e.*, without having recourse to the separate revolutions of the uchcha, and moreover it might be said that Varáha Mihira who reproduces the systems of his predecessors in a greatly condensed shape may have modified the rules of the Romaka Siddhánta in this special point, merely aiming at giving rules the results of which would be identical or nearly identical with those of the Romaka. But against this it is to be urged that in the next following chapter which treats of the calculation of eclipses according to the Súrya Siddhánta we meet with a rule for calculating the place of the uchcha which exactly agrees with the Súrya Siddhánta as known to us, and that therefore Varáha Mihira who faithfully reports the doctrine of one Siddhánta regarding this particular point may be expected to have done the same with regard to the other. Remembering therefore that in other points also, as shown above, the Romaka Siddhánta evinces more unmistakeable traces of Greek influence than the remainder of the Siddhántas, we shall most probably not err in considering its peculiar method of calculating the moon's mean anomaly as due to Greek models, while on the other hand the employment of separate revolutions of the uchcha as exhibited in the Súrya Siddhánta, etc. has to be viewed as an Indian innovation.

The rates of mean motion of the moon and her uchcha can of course be deduced from the rules extracted and translated in the above; they are, however, specially stated in another verse of the same chapter :

खनवनगाः शशिभुक्तिः कृतवसुमुनयः शशाङ्ककेन्द्रस्य ।

"The (mean daily) motion of the moon is 790 (minutes) ; of the moon's anomaly 784 (minutes)."

These are of course mere "sthúla" values, of sufficient accuracy, however, for ordinary purposes.

The value of the anomalistic month which results from Hipparchus's lunisolar periods is $27^d\ 13^h\ 18'\ 34{\cdot}7''$. The small difference between this value and the one adopted by the author of the Romaka Siddhánta may be owing to the latter's wish to establish a not over long period containing integral numbers of revolutions of the kendra and of civil days.

We finally have to consider a verse which contains the rule for calculating the mean place of the moon's node. The latter part of the text of the verse is very corrupt :

त्र्यष्टकगुणिते दद्याद्रसर्तुयमषट्कपञ्चकान् राहोः ।
भवरूपाग्न्यष्टिहृते क्रमादुखान्तोच्यते वक्रं* ॥

We are concerned only with the first half of the first line and the first half of the second line. The second half of the first line states the kshepa whose consideration we exclude; the second half of the second line is corrupt (the वक्रं, however, clearly indicates that the motion of the node is retrograde). "Tryashṭaka" has to be taken as meaning 24. The rule therefore directs us to multiply (the ahargaṇa) in the case of Ráhu by 24 and to divide by 163,111. From this it appears that the Romaka reckons 24 revolutions of the node to 163,111 days; one revolution therefore comprises 6,796^d 7^h. This agrees very nearly with Ptolemy's determination (which we calculate from the mean daily motion of the node as determined by him) according to which one revolution of the node takes place in 6,796^d 14^h, etc.†

From these statements regarding the yuga of the Romaka Siddhánta we now turn to the practical rule concerning the calculation of the ahargaṇa which is contained in the 8th, 9th and 10th verses of the first chapter where it follows immediately on the introductory verses quoted and translated above.

सप्ताश्विवेदसंख्यं शककालमपास्य चैत्रशुक्लादौ ।
अर्धास्तमिते भानौ यवनपुरे सौम्यदिवसाद्ये ।
मासीकृते समासे द्विष्ठे सप्ताहते ऽष्टयमपक्षैः ।
लब्धैर्युतो ऽधिमासैस्त्रिंशद्घ्नस्तिथियुतो द्विष्ठः ।
रुद्रघ्नः समनुशरो लब्धोनो गुणखसप्तभिर्द्युगणः ।
रोमकसिद्धान्ते‡ ऽयं नातिचिरे पौलिशे ऽप्येवम् ॥

"Deduct the S'aka year 427, (*i. e.*, deduct 427 from the number of that S'aka year for any day in which you wish to calculate the ahargaṇa) at the beginning of the light half of Chaitra, when the sun had half set

* So in B. A. has over क्रमा a rather indistinctly shaped letter which may be a इ or perhaps an र and after that खांत्यते.

† We may notice here a mistake which has crept into the Comparative Table of the Sidereal Revolutions of the planets in Burgess—Whitney's translation of the Súrya Siddhánta, p. 168. The compiler of that Table when calculating the sidereal revolution of the node according to Ptolemy and the moderns apparently forgot that, the motion of the node being retrograde, the effect of the precession of the equinoxes is to render the sidereal revolution of the nodo not longer but shorter than the tropical revolution; he therefore added the difference due to the precession to the tropical revolution instead of deducting it. The real value of the sidereal revolution of the node according to the moderns is 6,793^d 10^h, etc., and rather less than this quantity according to Ptolemy.

‡ A. B. °सिद्धान्तो.

in Yavanapura, at the beginning of Wednesday; turn (the number of solar years remaining after the deduction of 427) into months, add the months, (*i. e.*, the elapsed lunar months of the current year), put the result down in two places, multiply it (in one place) by 7 and divide by 228, add the resulting adhimásas (to the number of months obtained above); multiply the sum by 30, add the tithis, (*i. e.*, the elapsed tithis of the current month), put the result down in two places; multiply it (in one place) by 11, add 514 and (divide) by 703; deduct the quotient (from the number of tithis found above). The final result is the (sávana) ahargaṇa according to the Romaka Siddhánta; in the Pauliśa too it is not very much different."

The above is a very concisely stated rule for a rough calulation of the ahargaṇa, *i. e.*, the sum of civil days elapsed from a certain epoch down to a given date. The general principles of the calculation do not differ from the usual ones and therefore stand in no need of elucidation. Concerning the details we have in the first place to notice that the S'aka date 427 has to be deducted from the given sum of years. This means of course that the ahargaṇa is to be calculated from the end of the 427th year of the S'aka era. The question remains whether 427 S'aka elapsed is to be taken as the time when the Romaka Siddhánta was written or at least is the epoch fixed upon by the author of the Romaka Siddhánta as the starting-point of his calculations, or whether the named year represents either the time of the composition of the Pañchasiddhántiká or the epoch selected by Varáha Mihira himself. The former alternative is indeed *primâ facie* the much more probable one as the date appears in the text in connexion with other details which certainly originally belonged to the Romaka and not to Varáha Mihira. The latter alternative can, however, not be rejected altogether; for it is by no means impossible that while the principles of the calculation of the ahargaṇa are taken from the Romaka, the particular date from which it starts might have been chosen by Varáha Mihira himself. It is moreover the habit of the writers of karaṇa-granthas to take for their epoch either the year in which their book is actually composed or at least some very near year. And finally Albírúní as well as the Hindú Astronomers of Ujjain who in the beginning of this century furnished Dr. W. Hunter with the list of astronomers published by Colebrooke (Algebra, p. xxxiii) took 427 as the date of Varáha Mihira himself (*Cf.* Kern, Preface to the Bṛihat Saṃhitá, p. 2.) On the other hand as Prof. Kern points out, it is certainly most improbable that Varáha Mihira whose death has been ascertained by Dr. Bhau Daji to have taken place in 587 A. D. should have written the Pañchasiddhántiká in 505 already. The other argument adduced by Prof. Kern against 505 being the date of the Pañchasiddhántiká is that the latter work quotes Árya Bhaṭa who was born in 476 only and therefore is not likely to have been referred to in 505 already as a writer of authority. Matters lie, however, somewhat differently. We know from a passage of Brahmagupta which will be quoted later on, that S'ríshena the author of the Romaka Siddhánta had borrowed some of the fundamental principles of his astronomical system from Áryabhaṭa. Now Áryabhaṭa's first work (for it is not likely that he began to write before the age of twenty-three) having been composed in 499, the assumption that 505 marks the time of the Pañchasiddhántiká would compel us to conclude that S'ríshena's work was written in the short interval between 499 and 505, and had then already become famous enough to be esteemed one of the principal five Siddhántas. Such a conclusion does certainly not recommend itself, and we may safely I think assume that 505 is either the year in which S'ríshena's work was written or else the year selected by him for the starting-point of his calculations, and therefore not far remote from the year in which he wrote. For the date of the Pañchasiddhántiká there would finally remain the period from 505 to 587. I should, however, be unwilling to assign it to a later date than perhaps 530 to 540; for if its composition was removed by too great an interval from 505, it is improbable that Varáha Mihira should have kept the latter year as his epoch and not have introduced a more recent one.

We return to the ahargaṇa rule. The days are to be counted from sunset, a practice which we do not elsewhere meet with in India while it is known to have been generally followed by the Greeks; another proof for the particularly intimate dependance of the Romaka on Greek science. The years which have elapsed from the epoch are turned into months (in the usual way, by being multiplied by 12) and the elapsed months of the current year are added. Then by a proportion resulting from the yuga of the Romaka the intercalary months are calculated (7 intercalary months are to be added to 228 months; how many to the given number of months?). The number of the months is then multiplied by 30, and from the number of tithis found in that way the number of omitted lunar days (tithi kshaya) is derived by another proportion, which is, however, merely approximate. Since, as we have seen above, the Romaka reckons 16,547 omitted lunar days to the yuga (which comprises 1,057,500 tithis), 703 lunar days comprise $11 + \frac{41}{1057500}$ omitted lunar days, while the proportion made use of for the calculation of the ahargaṇa neglects the fraction. The additional quantity 514 does not occupy us because, as stated above, we exclude for the present the consideration of the epoch of the Romaka Siddhánta and the kshepa-quantities connected with it.

An identical rule for the calculation of the ahargaṇa is not found anywhere else in Indian astronomy (as indeed it cannot be on account of the prevailing employment of the sidereal solar year) with one exception. The rules of Siamese astronomy which have been alluded to above teach the calculation of the ahargaṇa (or as it is called there horoconne—I quote from the account of Siamese astronomy given by Bailly in his Traité de l' astronomie Indienne et Orientale) according to exactly the same method. The kshepa-quantities differ on account of the Siamese rules starting from a different epoch. But the proportions $\frac{7}{228}$ and $\frac{11}{703}$ are both made use of. The use of the latter proportion is of no particular interest; for the proportion is only approximately correct, and does not allow of any certain inference regarding the length of the synodical month being founded on it. It is in fact—if I am not mistaken—occasionally used by karaṇa writers who deal with the sidereal year only. But the former proportion as clearly pointing to a tropical solar year is noteworthy, all the more as the Siamese rules nowhere directly acknowledge the tropical year but uniformly employ the sidereal one. It did in fact not escape the attention of Cassini who inferred from it that a tropical year of $365^d\ 5^h\ 55'\ 13''\ 46'''$ had originally been known to the Siamese, and remarked that such a year differed by two seconds only only from Hipparchus's year. We are now able to maintain that the two years originally did not differ at all, and that the later small divergence is merely due to the inaccurate proportion $\left(\frac{11}{703}\right)$ which for reasons of convenience was preferred to the accurate one.

We finally have to consider an interesting stanza in the 11th chapter of Brahmagupta's Sphuṭa Siddhánta which contains some information about the sources from which the elements of the Romaka Siddhánta were derived. The two manuscripts of the Sphuṭa Siddhánta at my disposal are unfortunately so incorrect that only a part of the stanza is intelligible; what interests us more particularly can, however, be made out I think. One manuscript (containing the text of the Sphuṭa Siddhánta only) reads:

युक्त्यार्यभटोक्तानि प्रत्येकं दूषणानि येाज्यानि ।
श्रीखेनप्रभृतीनां कानिचिदन्यानि वक्ष्यामि ॥
लाटात्सूर्यशशाङ्कौ मध्याविन्दूच्चपातौ च ।
कुजबुधशीघ्रबृहस्पतिसितशीघ्रशनैश्वरान् मध्यान् ।
युगपातवर्षभगणान् वासिष्ठाश्देन युगादिक्षतपाढात् ।
मन्दोच्चपरिधिपात्तस्पष्टीकरणाद्यमार्यभटात् ।
श्रीषेणेन गृहीत्वारत्नोच्चपरोमकात्त् क्षतः कंथा ।

The other manuscript (E. J. H. 1304) which contains parts of the Sphuṭa Siddhánta with the commentary by Prithúdaka Svámin reads:

Comm.: यानि संभवंति तान्यार्यभटदूषणानि श्रीषेणादीनां योज्यानि इत्येतदार्ययाह ।
Text: युक्त्यार्यभटोक्तानि प्रत्येकं दूगणानि योज्यानि ।
श्रीषेणप्रभृतीनां कानिचिदन्यानि वक्ष्यामि ॥
Comm.: गतार्थेयमार्या। इदानीं श्रीषेणाचार्येण कृतो रोमकसिद्धांतो यस्य वासिष्ठो विष्णुचंद्रेण यतो दूषणमार्याचतुष्टयेनाह ।
Text: आर्यान्सूर्यशशांकौ मध्याविंदूच्चचंद्रपातौ च । कुजबुधशीघ्रबृहस्पतिसितशीघ्रसनिस्वरान् मध्यान् । युगयातवर्षं भगणान्वासिष्ठान्विजयनंदिकृतपादान् । मंदोच्चपरिधिपाः तान्स्पष्टीकरणाद्यमार्यभटात् । श्रीषेणेन गृहीत्वा रत्नोच्चरारोमककृतकथेः इत्यादि ।

What chiefly concerns us in the above extract (the text of which it is not possible to emendate in all places without the help of further manuscripts) is the fact of Áryabhaṭa and Láṭa being mentioned among the predecessors of S'rísheṇa. The Romaka Siddhánta, in that shape at any rate which was given to it by S'rísheṇa, is therefore later than Áryabhaṭa and was as we have remarked above most probably composed in 505. It borrowed from Áryabhaṭa, as we see from the line मंदोच्च०, all those processes which are required for finding the true places of the planets. On the other hand it adopted from Láṭa all those rules by means of which the mean places of the planets are calculated.* Láṭa therefore appears to have been that Hindú astronomer who first borrowed from the Greeks the tropical year of Hipparchus, the Metonic period, etc. This would agree very well with the other notice, quoted above, which the Pañchasiddhántiká furnishes concerning Láṭáchárya, *viz.*, that according to him the beginning of the day was to be reckoned from the moment of sunset in Yavanapura. It is greatly to be regretted that the Pañchasiddhántiká does not treat of the mean motions of the planets other than sun and moon according to the Romaka Siddhánta; as these also were, according to Brahmagupta, borrowed from Láṭa they would most likely correspond with the mean motions as determined by Hipparchus more closely than the mean motions resulting from the cycles of the Súrya Siddhánta and the Áryabhaṭíya. If the Romaka Siddhánta by S'rísheṇa was composed in 505 as appears very likely Láṭa would have to be considered at least as a contemporary of Áryabhaṭa; but considering the specifically Greek character of his astronomy I think it much more likely that he preceded him.

* The reading आर्यान्सू० of the E. J. H. manuscript (instead of लाटात्सू० of the other manuscript) is clearly wrong. In the first place Árya could hardly be used for Áryabhaṭa; secondly, the mean motions of the Romaka are not those of Áryabhaṭa; thirdly, the indebtedness of the Romaka to Áryabhaṭa is stated in the later line मंदोच्चपरि०

A doubt concerning Láṭa's position might arise from the introduction of the Pañchasiddhántiká in which it is remarked that the Pauliśa and Romaka Siddhántas were "vyákhyátau" by Láṭadeva. This Láṭadeva is either to be considered as a writer altogether different from that Láṭa to whom S'rishena was indebted for a part of the elements of his Siddhánta, or else we must suppose that S'ríshena's Romaka Siddhánta was only a recast of an older Romaka Siddhánta which was written or commented on by Láṭa. The latter remark perhaps applies to the Pauliśa Siddhánta also, and we must here remember that, as Prof. Kern has shown, Utpala distinguishes between the Pauliśa Siddhánta and a Múla Pauliśa Siddhánta.

We may in conclusion sum up in a few words the chief results following from the consideration of those parts of the Pañchasiddhántiká which form the subject of this paper. In the first place it appears that the rules of the Súrya Siddhánta known to Varáha Mihira differed very considerably from the corresponding rules of the Súrya Siddhánta which has come down to us while they agreed partly with the A'ryabhaṭíya partly with the Pauliśa Siddhánta as represented by Bhaṭṭotpala. It follows that in any inquiries into the earliest history of modern Indian astronomy the existing Súrya Siddhánta is not to be referred to, at any rate not without great caution. In the second place we are enabled, by what we have learned about the Romaka Siddhánta, to go back beyond A'ryabhaṭa and the Súrya Siddhánta, and to gain an insight into the very beginning of modern Hindú science when it still wore the unmistakeable impress of its Greek prototype and had not yet hardened into its distinctive national form.

APPENDIX.

I take this opportunity of showing by some more examples how practical Hindú works on astronomy facilitate their calculations by at first employing greatly reduced numbers and afterwards making up for the resulting errors by applying corrections. In the astronomical tables alluded to in the preceding paper which Bailly calls the tables of Narsapur, a period is employed for the calculation of the moon's mean place which is yet considerably simpler than the one which according to Varáha Mihira may be constructed on the elements of the Súrya Siddhánta We are there directed to multiply the ahargaṇa by 800 and to divide by 21,857. Eight hundred revolutions of the moon comprising 21,857 days, one revolution would be equal to $27^d\ 7^h\ 42'\ 36''$. But a correction is stated to the effect that the given ahargaṇa is to be divided by 4,888 and the quotient, taken as indicating degrees, is to be deducted from the mean place of the moon as found from the general rule. This is as much as saying that $\frac{1}{4888}^\circ = 0{\cdot}7365''$ for each day of the ahargaṇa are to be deducted. Multiplying this quantity by the duration of the periodical month as stated above ($27^d\ 7^h$ etc.) we obtain 20·1218″. So many seconds of the circle are passed through by the moon in 36·65″. We add the latter quantity to the duration of the month and thus obtain $27^d\ 7^h\ 43'\ 12{\cdot}65''$, which is almost identical with that duration of the sidereal month which results from the elements of the published Súrya Siddhánta and differs very little only from the duration of the month presupposed by the Súrya Siddhánta of the Pañchasiddhántiká. Bailly supposes that that estimation of the month which results from 800 revolutions being considered equal to 21,857 days was the original one, and that the stated correction was added later for the purpose of bringing about an equality between the results of the tables of Narsapur and the tables of Kṛishṇapur (whlch are likewise described by Bailly, Traité, etc., p. 31 *ff.*). But matters have doubtless to be explained differently. The author of the tables of Narsapur was acquainted with the Súrya Siddhánta from which he derived his knowledge of the length of the sidereal month. He, however, aimed at replacing the inconveniently big numbers of the Súrya Siddhánta by smaller ones—in the same way as Varáha Mihira does in his account of the Súrya Siddhánta, went, however, a step further than the latter astronomer by reducing the period of 900,000 revolutions to its 1125th part, *i. e.*, 800 revolutions. Dividing the 24,589,506 days of the former period by 1,125 we get $21857 + \frac{381}{1125}$. The moon's mean place is then calculated at first without the fraction being taken into account; but the error arising from this neglect is too considerable to be neglected, and so the above stated correction is applied finally.—We have to account in an analogous manner for the origin of the correction of the sun's mean place which the tables of Narsapur apply (Bailly, p. 54). The period comprising 800 revolutions of the sun which is employed there immediately presupposes a year of $365^d\ 6^h\ 12'\ 36''$ while the year of the Súrya Siddhánta is longer by 0·56″. To make up for this difference 2″ for each period of 87 years are deducted from the sun's mean place as calculated from the 800 year period. For if the year has been estimated 0·56″ short of its real length the error amounts in 87 years to 48·7″, and in so much time the sun passes through two seconds of the circle. It thus appears that here again the correction had not the aim of reconciling two sets of astronomical tables but was contemplated by the author of the Narsapur tables at the outset.